Mg II / C IV KINEMATICS VS. STELLAR KINEMATICS IN GALAXIES

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Abstract

Comparisons of the kinematics of MgII absorbing gas and the stellar rotation curves in $0.5 \leq z \leq 1.0$ spiral galaxies suggests that, at least in some cases, the extended gaseous envelopes are dynamically coupled to the stellar matter. A strong correlation exists between the overall kinematic spread of MgII absorbing gas and CIV absorption strength, and therefore kinematics of the higher–ionization gas. Taken together, the data may suggest a "halo/disk connection" between $z \sim 1$ galaxies and their extended gaseous envelopes. Though the number of galaxies in our sample are few in number, there are no clear examples that suggest the gas is accreting/infalling *isotropically* about the galaxies from the intergalactic medium.

1. Extended Gaseous Envelopes: Halos or IGM?

For $0.5 \leq z \leq 1$, there are observed correlations between galaxy luminous properties and MgII absorption properties that support a view in which metal–enriched extended (~ 40 kpc) gaseous envelopes of normal bright galaxies are coupled to galaxies (e.g. Bergeron & Biossé 1991; Steidel et al. 1994; Steidel 1995). An alternative view, extracted from numerical simulations of cosmic structure growth, is that the gas is concentrated along intergalactic filaments, where matter overdensities also give rise to mergers and normal bright galaxies.

By $z \sim 1$, do galaxies remain coupled to the cosmic flow of baryons driven by matter overdensities or have they decoupled? If the latter, they likely sustain their gaseous envelopes via mechanical means within the galaxies. In this contribution, we present data that suggest the MgII absorption and the emission line kinematics are coupled in some galaxies. We also discuss the kinematic relationship between CIV and MgII and present the first galaxy for which data of the emission and MgII and CIV absorption kinematics are available.

2. Mg II Gas–Galaxy Kinematics

In Figure 1, we show schematics of quasar sightlines through galaxies. Two simplified kinematic models are illustrated: isotropic infall (left), to depict the IGM inflow, and disk rotation (right), to depict gas coupled to the stellar components. The sightlines pass through absorbing clouds whose velocity vectors are shown. Below each schematic is an absorption profile. All profiles are in the systemic rest–frame velocity.

The distribution of velocities for the infall model is symmetric about the galaxy systemic velocity and the profile is comprised of discreet, unblended absorption lines with a velocity spread comparable to the infall velocity. The disk model gives rise to a profile that is offset with both magnitude and sign dictated by rotation and is comprised of a complex blend with a varying optical depth spread over a narrow velocity range. If the sightline passes through both infalling and rotating components, the profile would appear as shown in the bottom central panel. These distinct absorption/kinematic signatures of infalling and rotating gas serve as a guide for discriminating scenarios of the nature of extended gaseous envelopes around galaxies (for additional details see Charlton & Churchill 1998).

Steidel et al. (2002) compared the emission–line (stellar) rotation curves of five highly inclined spiral galaxies to their MgII absorption kinematics. In four of five galaxies, the absorption profiles are suggestive of "disk–like" dynamics, exhibiting properties of the disk model (Figure 1). The fifth galaxy exhibits a single, weak MgII absorber (see Churchill et al. 1999a) at the galaxy systemic velocity. There was no example of discreet clouds distributed symmetrically about the galaxy systemic redshift. However, detailed interpretation of the absorption kinematics is, in reality, not clear. It is difficult to understand the spatial geometry of the gas for the observed kinematics, the high galaxy inclinations, and the large impact parameters.

These systems serve as evidence that, at least in some cases, the extended gaseous envelopes around galaxies appear to be coupled to the

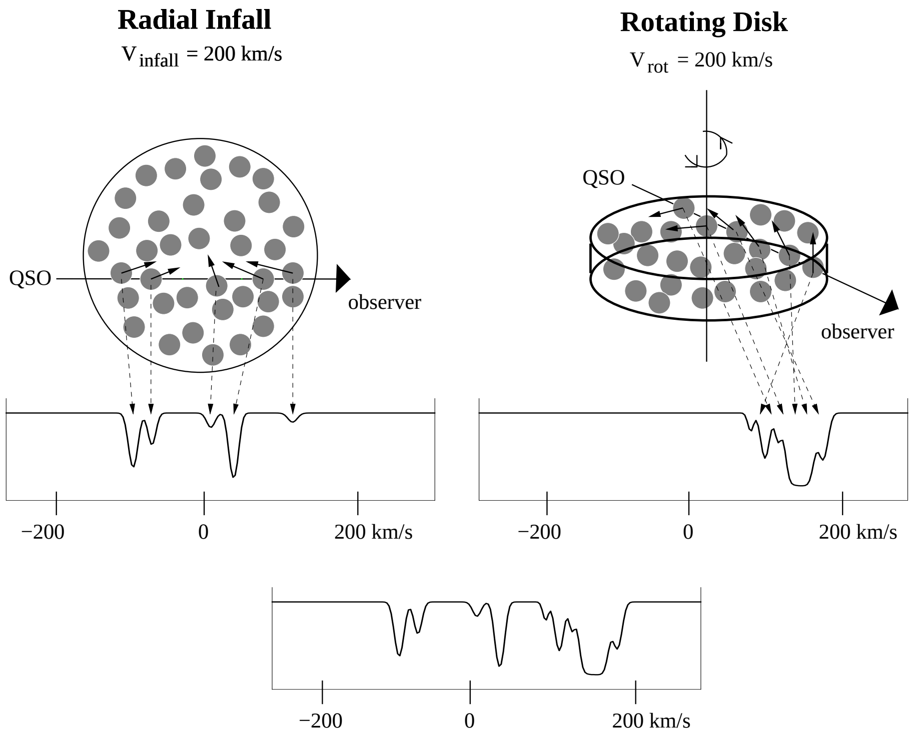

Figure 1 — Schematic kinematic models for absorbing gas. The left panels show an isotropic infall model and profile (i.e. IGM accretion); the right panels show the disk rotation model and profile (i.e. gas coupled to stellar kinematics). The lower panel is the combined absorption profile. The velocity zero point is the galaxy systemic redshift.

emission–line kinematics. To be fair, it cannot be ruled out that non–isotropic IGM accretion could have the general sense of galactic rotation.

3. Clues from C IV Absorption

The kinematics of MgII and CIV are strongly correlated (Churchill et al. 1999b). Churchill et al. suggested that this correlation could arise if the gas spatial and kinematic distribution reflected a disk/halo connection similar to those in local galaxies (see Dahlem 1998, and references therein). This is consistent with the gas having a multiphase ionization and kinematic structure (e.g. Bergeron et al. 1994; Churchill et al. 2000a, 2002b).

To better understand this MgII–CIV kinematics correlation and the multiphase structure, we have observed the CIV with STIS/HST (E230M, $R = 30,000$). In Figure 2, we present four selected systems, S1–S4. For each, the top panel shows the MgII λ2796 transitions (HIRES/Keck, $R = 45,000$) and the lower panel shows the CIV λ1548 transition in rest–frame velocity (zero points are arbitrary). The four MgII profiles were specifically selected to illustrate the disk–like kinematic signature. Observationally, this signature is common— in a sample of 23 MgII systems, only one system exhibited absorption symmetrically about the strong complex (Churchill & Vogt 2001).

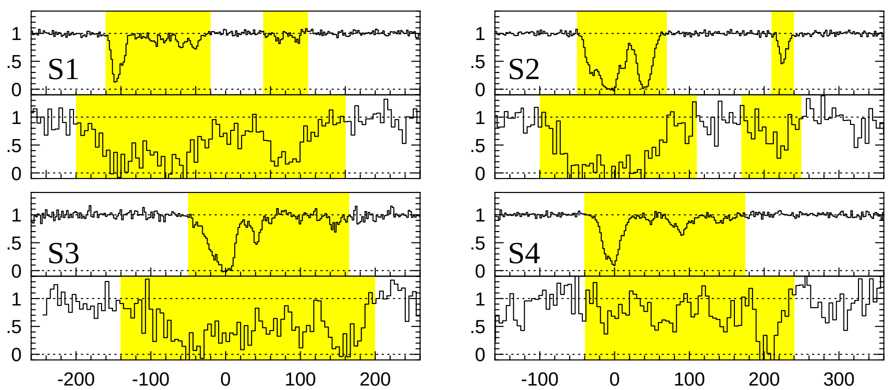

Figure 2 — The MgII λ2796 (HIRES/Keck) and CIV λ1548 (STIS/HST) absorption profiles for four selected systems. The profiles are presented in rest–frame velocity, where the zero point has been set arbitrarily.

In systems S1 and S2, the CIV kinematically traces the MgII, though the CIV has less substructure (broader components). The bulk of the CIV arises in a lower density phase, possibly supported by turbulence. These could be coronal structures similar to that of our Galaxy (e.g. Savage et al. 1997). System S3 is similar to S1 and S2, except that the strongest CIV component is offset in velocity where the MgII is very weak. Further, the component is relatively narrow. System S4 is unique in that the CIV is highly structured with the MgII absorption but has a strong, very narrow CIV component where there is no observed MgII. This is a quiescent high ionization"CIV–only cloud". The widths of these CIV–only clouds would be substantially broader if they were Galactic–like corona or shock heated infalling material.

4. Q1317+227 at $z = 0.66$: A Case Study

S4 is the $z = 0.6610$ absorber along the Q1317 + 277 sightline. In Figure 3*a*, we present the WFPC2 image of the quasar field showing two galaxies, G1 and G2. LRIS/Keck spectra of these galaxies were obtained with the slit aligned as shown by the vertical lines. The redshift of G2 matches the absorption redshift; its rotation curve is shown in the upper panel of Figure 3*b*, below which are the MgII λ2796 and CIV λ1548 absorption profiles.

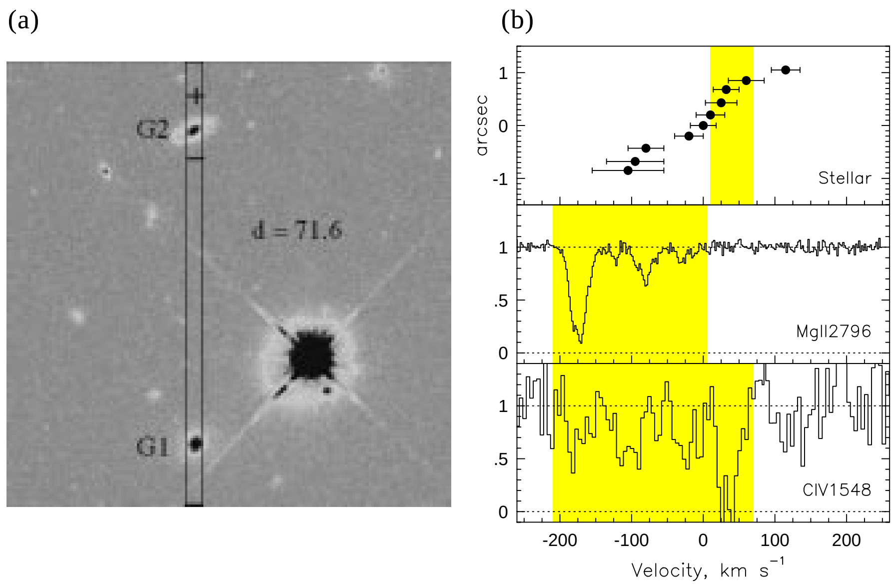

Figure 3 — (*a*) A WFP2 image of the Q1317 + 277 field, showing the $z = 0.6610$ galaxy (G2). Vertical lines show slit placement for the galaxy spectra. — (*b*, top to bottom) The emission–line velocity profile of G2; the MgII λ2796 absorption profile; and the CIV λ1548 absorption profile. The velocity zero point is the systemic velocity of G2.

At face value, the MgII kinematics are suggestive of the disk kinematic model. The strongest MgII is aligned with the stellar rotation and the weaker clouds are not symmetry about the galaxy systemic velocity. However, detailed modeling reveals that a simple disk scenario fails; this system is very puzzling (Steidel et al. 2002). At a projected distance of $\sim$ 72 kpc, the nature of the narrow CIV–only cloud, which is slightly positive with respect to the galaxy systemic velocity (shaded region on the stellar velocity curve), is also difficult to understand in view of the overall absorption kinematics. What is the nature and origin of the quiescent high ionization gas at a distance of 70 kpc having a nearly galactic systemic velocity?

5. Discussion

If galaxy evolution to the present epoch is governed by the accretion of gas from the IGM, the gas would provide a tracer of the structure, kinematics, and chemical enrichment of the cosmic web. The gas would not necessarily be coupled to galaxy emission–line kinematics in the majority of cases; neither merging events nor IGM accretion predict strong coupling between the gas kinematics and the stellar kinematics. A large statistical sample is needed to discern the veracity of this expectation.

What scenario, then, can predict the observed coupling between the kinematics of the extended gas envelopes and the galaxy stars? Following a merging event, star formation rates are elevated long after the stellar system has relaxed. Supernovae inject gas into the halos of their host galaxies. This scenario naturally provides for the expulsion of gas from galaxies that is metal enriched and harbors some memory of the dynamical state of the stellar component of the galaxies.

Acknowledgments

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References

Bergeron, J. et al. 1994, ApJ, 436, 33
Bergeron, J. & Biossé, P. 1991, A&A, 243, 334
Charlton, J. C. & Churchill, C. W. 1998, ApJ, 499, 181
Churchill, C. W. et al. 1999a, ApJS, 120, 51
Churchill, C. W. et al. 1999b, ApJ, 519, L43
Churchill, C. W. et al. 2000a, ApJS, 130, 91
Churchill, C. W. et al. 2000b, ApJ, 543, 577
Churchill, C. W. & Vogt, S. S. 2001, AJ, 122, 679
Dahlem, M. 1998, PASP, 109, 1298
Savage, B. D., Sembach, K. R., & Lu, L. 1997, AJ, 113, 2158
Steidel, C. C. 1995, in QSO Abs. Lines, ed. G. Meylan (Garching: Springer), 139
Steidel, C. C., Dickinson, M., & Persson, E. 1994, ApJ, 437, L75
Steidel, C. C. et al. 2002, ApJ, 520, 526